Economic analysis of the end-of-life of public school buildings structures

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Abstract

The present work applies the methodology of life-cycle cost analysis (LCCA), proposed by the standard EN 16627, to a portfolio of public school buildings in Portugal built between 1946 and 1992, rehabilitated by Parque Escolar, EPE in 2010. The analysis pertains to the end-of-life stage of buildings, assuming that they have reached the end of their life-cycle with the rehabilitation interventions. As part of the application of the LCCA methodology, waste management costs are captured, associated with the diverse end-of-life stages of buildings, from their deconstruction to the processing or disposal of the produced waste. Cost compilation is based on public and private databases and companies operating in the sector, in order to establish a set of values applicable in any school building. The analysis of the collected information allows the foundation of reference values for the different phases. For the several elements of the concrete structure are obtained unit cost for deconstruction between 41€/m^3 and 209€/m^3 and for inert waste a unit cost for transport of 13€/m^3, a unit cost for wastes processing of 18€/m^3 and a unit cost for disposal of 15€/m^3. It is also possible to validate these reference values by applying them to a school that belongs to the portfolio, obtaining a net present value (NPV) for the end-of-life of concrete structures, for the scenario considered, of 133.453€.

Key-words: *Life-cycle costs analysis, end-of-life stage, school buildings, data base, reference value, construction and demolition waste*

1. Introduction

Life Cycle Cost (LCC) concept is used in the construction sector not only as an engineering tool, but also as a management tool, concerning to cost analysis in particular. LCC methodology promotes the relationship between both aspects, improving asset management and supporting the decision making in the future (Assis & Julião, 2009). The use of the LCC methodology in buildings has increased in the asset management at a national and international level, and there are already several standards that aim at its application, such as ISO 15686-5 (2014), EN 15643-4 (2012) and EN 16627 (2015), on which the present study is based.

This work aims to apply the LCC methodology to the end-of-life stage of a portfolio of public school buildings, which includes several economic variables with associated uncertainty, such as waste processing for reuse, recovery or recycling and waste disposal, collecting and analyzing economic data in order to obtain reference values for the costs associated with the end-of-life stage. This study also pretends to test this results, applying them on a school building.

2. Knowledge review

LCC is a method of analyzing and optimizing the total cost of an asset, aiming to influence the change to a proactive position in the company's cost policy, allowing the prediction of total costs associated with the assets during their life-cycle. LCC and Asset Management are essential concepts as the impact of the investment made on an asset is deducted by the LCC, and not by the initial investment value, since the long-term operation and maintenance costs of a building can exceed the initial investment (Assis & Julião, 2009).

Asset Management is the coordinated activity of the organizations, in order to realize value from their physical assets, from a balance between costs, risks, opportunities and performance benefits, from its planning and design phase to the end-of-life. A physical asset is something that has potential or actual value to an organization (ISO 55000, 2014).

The LCC methodology is regulated by ISO 15686-5 (2014), which refers that the analysis has influence in the decision making at several levels, indicating that the greatest potential of influence is in the planning and the design phases, as shown in Figure 1, since the opportunity to influence the design and construction options becomes increasingly limited at later stages of the asset's life.

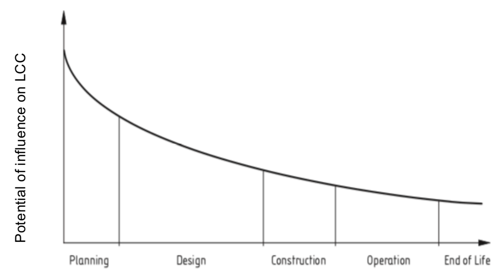

Figure 1: Potential influence on LCC – adapted from ISO 15686-5 (2014).

The standard EN 15643-4 (2012) divides the life-cycle into three phases relevant to the analysis, with the following designations: module A - before use stage, module B - use stage and module C – after use stage, detailed in Figure 2.

The present work pretends to apply the LCC methodology to the end-of-life stage (module C),

BUILDING ASSESSMENT INFORMATION			
BUILDING LIFE CYCLE INFORMATION			
MODULE A **BEFORE USE STAGE**	**MODULE B** **USE STAGE**	**MODULE C** **AFTER USE STAGE**	**MODULE D** **Benefits and loads beyond the system boundary**
PRE-CONSTRUCTION **A0** - Land and associated fees/advice PRODUCT STAGE **A1** - Raw material supply **A2** - Transport **A3** - Manufacturing CONSTRUCTION PROCESS **A4** - Transport **A5** - Construction - Installation process	USE STAGE B1 - Use B2 - Maintenance B3 - Repair B4 - Replacement B5 - Refurbishment B6 - Operational energy use B7 - Operational water use	END-OF-LIFE STAGE **C1** - Deconstruction **C2** - Transport **C3** - Waste processing for reuse, recovery or and recycling **C4** - Disposal	SUPPLEMENTARY INFORMATION BEYOND THE BUILDING LIFE CYCLE Reuse, Recovery, Recycling potential

Figure 2: Information modules applied in the assessment of economic performance of a building – adapted from EN 15643-4 (2012).

which starts when the building or part of it is decommissioned and is not intended for any other use. Deconstruction or demolition of a building leads to a source of materials that must be recovered, recycled, reused or disposed, generating costs related to the end-of-life operations.

According to the standard EN 16627 (2015), for the calculation methods of economic end-of-life performance of buildings, the following cost components must be considered:

Module C1: covers both the deconstruction and the demolition process, including on site operations and operations undertaken in temporary works located off site as necessary for the deconstruction processes, after decommissioning up to and including on site deconstruction, dismantling and/or demolition.

Module C2: embraces costs due to materials transport for disposal or until the end-of-waste state is reached, which means that the recovered material is used for specific purposes. This module also includes transport costs to and from possible intermediate storage/processing locations.

Module C3: refers to waste processing costs, incurred by on site operations and operations undertaken in temporary works located off site to process waste. The regarded scenarios should describe waste treatment processes, such as sorting, preparatory processes for reuse, recycling and energy recovery, up to the moment where the output from dismantling, deconstruction or demolition of the building or construction works ceases to be waste.

Module C4: quantifies all costs resulting from the final disposal of materials, including their neutralization, incineration or landfilling. It also includes the possible post-transportation treatment that is necessary before disposal.

Any income which is received by the building owner from the sale of the land, waste processing for reuse, recovery or recycling or waste disposal process is assigned to Module D, which is not included in the analysis to be carried out within this work. This study considers only the costs associated with the physical assets, not including its incomes.

3. Methodology

The standard EN 16627 (2015) includes the necessary bases for the assessment of economic performance of school buildings. Based on the standard, Table 1 shows a methodology for LCC calculation, adapted to the scope of the present study. The scope of the proposed methodology excludes risk/uncertainty and sustainability analysis, as well as sensitivity analysis.

Table 1: Steps of the analysis methodology – adapted from EN 16627 (2015).

Steps of the methodology	Clauses of EN 16627
1) Purpose of the LCCA	6.1
2) Scope of the LCCA	6.1- 6.2 - 7.1
3) Period of analysis and methods for the economic performance assessment	7.3 - 10 - 11
4) Project and asset requirements	7.4 - 8
5) Options and costs to be considered	9
6) Collection of costs and periods of occurrence	7.4 - 9 - 10
7) Verification of economic parameters and the period of analysis	10
8) Assessment of economic performance	11
9) Interpretation and presentation of initial results	12
10) Presentation of final results	12

4. Case study

4.1. Portfolio of public school buildings

The case study covers a portfolio of public school buildings in Portugal built between 1946 and 1992, rehabilitated by Parque Escolar, E.P.E. in 2010. Of all 69 rehabilitated buildings, this study covers those that had structure demolitions, in particular demolitions of concrete structure elements. This initial process resulted in a portfolio of 51 school buildings, which end their life-cycle period in 2010 when the buildings were totally or partial refurbished.

76% of the buildings were built between 1968 and 1992, with a significant incidence in the 1980s, corresponding to a period of school network expansion. Thus, about 80% of the sample has pavilion typology, which was a *standardized design* solution. All buildings are characterized by reinforced concrete structure.

The same type of intervention was verified in all the school buildings studied: remodeling of existing facilities, improvement of interior and exterior coverings, maintenance of structural conditions, improvement of sports spaces and execution of external arrangements.

4.2. Application of the LCC methodology

The proposed LCC methodology is applied to the portfolio of school buildings considered, collecting and processing economic information based on the steps and requirements presented previously, including the costs shown in Table 2.

Demolition costs were collected from ProNIC database, which is a tool that documents costs related to the rehabilitation interventions of the different school buildings. The public database Gerador de Preços and companies from the waste management sector were also consulted.

This study considers a period of analysis of 8 years, between 2010 and 2018. To analyze the economic performance of the buildings, in addition to the total costs, the parameter Net Present Cost (NPC) was considered, suggested by the standard EN 16627 (2015), correcting all costs for the reference year 2018 and allowing comparisons between databases.

NPC is determined with a real discount rate of 3% (EN 16627, 2015). The discount factor should be calculated with equation (1):

$$DF\ (T) = \frac{1}{(1+r)^T} \qquad (1)$$

Table 2: Costs included in the end of life stage – adapted from EN 16627 (2015).

Costs included in the end of life stage (Module C)	
Cost category	**Costs included in category**
Deconstruction (C1)	Deconstruction/dismantling Demolition Fees and taxes
Transport (C2)	All transport costs associated with the process of deconstruction and disposal of the asset Fees and taxes
Waste processing for re-use, recovery and recycling (C3)	Costs from re-use, recycling and energy recovery at end of life Fees and taxes
Disposal (C4)	Disposal costs Fees and taxes

where r is the annual discount rate, T is the number of years between the reference date (2018) and the date of cost occurrence (2010). It should be noted that, when discounting past costs, the factor is the inverse to the one presented in equation (1).

Based on the discount factor (DF), NPC is calculated with equation (2):

$$NPC = \sum Ct_{n_{2018}} \times DF \qquad (2)$$

where $Ct_n(2018)$ represents the costs at constant prices, corrected for 2018, determined with equation (3):

$$Ct_{n_{2018}} = C_t \times \prod_{n}^{2018} (1 + i_n) \qquad (3)$$

obtained by multiplying the costs in the year of occurrence, collected in year n (when year n is previous to the reference year) and the factor that considers the inflation rate (i) of every year. Once again, it should be noted that when year n is posterior to the reference year, the inverse calculation is performed.

All costs collected due to the application of LCC methodology are associated with the year of occurrence and the source of information.

5. Results

Through ProNIC database, documents were consulted for each school building in the portfolio, aiming to gather information on the demolition of structural elements: demolition quantity and unit cost of the operation.

Some information was not included in the sample, since it did not verify the necessary requirements. Values for the demolition of several elements were obtained in the units of measurement *€/m³*, *€/m²* and *€/m*.

First of all, the elements were subjected to a statistical analysis, as shown on Tables 3, 4 and 5. In this study, for each element the sample outliers were excluded, due to their definition as abnormal values of a sample, which may cause irregular variations, prejudicing statistical results such as the mean value of the sample. Once excluded, mean results were closer to median results, being a more reliable result as the median value does not take into account the extreme values of the sample, providing a more robust measure than the mean value, that can be distorted by extremely high or low values.

As shown in Figure 3, the unit cost obtained for the demolition of slabs of beams (40,55€/m³) is lower than the unit cost for solid slabs (198,89€/m³), which is justified by the type of work, as the demolition process itself: the lightening blocks are removed first and then the

Table 3: Results obtained from the descriptive statistics of unit costs (€/m³).

Descriptive Statistics	Solid slab	Slab of beam	Ground floor	Beams	Pillars	Concrete walls	Stairs	Outer walls	Platbands
Mean	198,89	40,55	92,25	199,95	186,57	174,30	153,97	207,00	209,13
Standard Error	22,83	10,45	21,23	31,30	26,00	31,59	23,36	77,09	38,23
Median	159,51	32,61	85,07	159,51	155,96	166,60	141,78	141,78	187,86
Mode	313,27	-	28,36	313,27	313,27	28,36	141,78	56,71	-
Standard Deviation	111,87	23,38	63,69	146,82	119,17	109,41	112,02	172,37	76,46
Range	389,20	59,55	191,68	617,03	333,46	326,10	333,46	368,64	177,23
Minimum	21,27	11,34	21,00	21,00	21,00	28,36	21,00	56,71	141,78
Maximum	410,46	70,89	212,68	638,03	354,46	354,46	354,46	425,35	319,01
Count	24	5	9	22	21	12	23	5	4

concrete beams are demolished (Gomes, J. & Oliveira, F.).

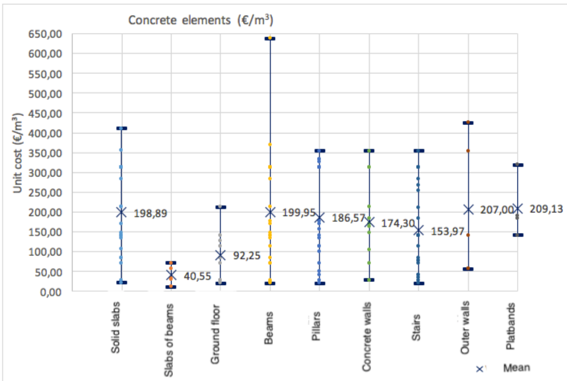

Figure 3: Unit costs for demolition (€/m³).

The same analysis was made for elements in the units of measurement *€/m²* and *€/m*, and the results are presented in Figures 4 and 5. It is important to note that, in terms of statistical analysis, the sample studied contains a reduced number of values.

Table 4: Results obtained from the descriptive statistics of unit costs (€/m²).

Descriptive Statistics	Solid slab	Slab of beams	Ground floor	Roof	Stairs
Mean	84,42	24,51	23,37	21,48	36,88
Standard Error	13,74	3,47	2,68	6,36	11,06
Median	74,46	28,36	21,98	17,01	34,03
Mode	-	28,36	28,36	-	35,45
Standard Deviation	43,46	9,18	11,38	14,22	29,26
Range	132,94	24,10	37,57	36,15	87,79
Minimum	28,36	11,34	4,96	6,38	11,46
Maximum	161,29	35,45	42,54	42,54	99,25
Count	10	7	18	5	7

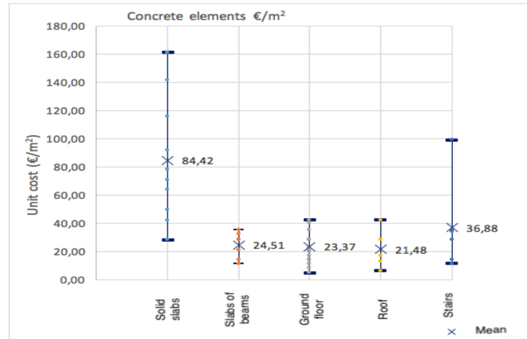

Figure 4: Unit costs for demolition (€/m²).

Table 5: Results obtained from the descriptive statistics of unit costs (€/m).

Descriptive Statistics	Sill	Outer walls
Mean	5,40	38,47
Standard Error	1,22	24,99
Median	6,10	13,82
Mode	-	-
Standard Deviation	2,12	49,98
Range	4,07	100,64
Minimum	3,02	12,79
Maximum	7,09	113,43
Count	3	4

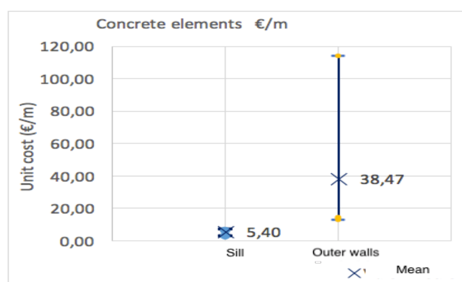

Figure 5: Unit costs for demolition (€/m).

When the values of unit costs are associated with the respective demolition quantities, the analysis concludes that costs tend to decrease for higher quantities while the highest values of unit cost, considered as outliers of the sample, correspond to lower demolition quantities.

Several *budget estimate* documents consulted, associated with the portfolio buildings, indicate that demolitions represent 1% to 3% of the total cost of the project.

Tables 6 to 9 show all the unit values collected in the scope of the present work. Values collected from Gerador de Preços database are from 2019 and were corrected to 2018 through equations (1), (2) and (3). Values collected from companies in the waste management sector correspond to the year 2018.

Table 6: Total costs of Module C1.

	Description	ProNIC (€/m^3)	Gerador de Preços (€/m^3)
C1	Demolition of solid reinforced concrete slabs	198,89	-
	Demolition of slabs of prestressed concrete beams	40,55	-
	Demolition of ground floor of reinforced concrete	92,25	-
	Demolition of reinforced concrete beams	199,95	317,25
	Demolition of reinforced concrete pillars	186,57	317,25
	Demolition of reinforced concrete walls	174,30	-
	Demolition of reinforced concrete stairs	153,97	-
	Demolition of reinforced concrete outer walls	207,00	162,20
	Demolition of reinforced concrete platbands	209,13	-
	Description	**ProNIC (€/m^2)**	**Gerador de Preços (€/m^2)**
	Demolition of solid reinforced concrete slabs	84,42	65,00
	Demolition of slabs of prestressed concrete beams	24,51	53,69
	Demolition of ground floor of reinforced concrete	23,37	19,14
	Demolition of reinforced concrete roof	21,48	-
	Demolition of reinforced concrete stairs	36,88	44,92
	Description	**ProNIC (€/m)**	**Gerador de Preços (€/m)**
	Demolition of reinforced concrete sills	5,40	-
	Demolition of reinforced concrete outer walls	38,47	-

Table 7: Total costs of Module C2.

	Description	Gerador de Preços (€/m^3)	Companies (€/m^3)
C2	Transport of inert waste with container	20,93	13,04
	Transportation of inert waste with lorry	3,41	-

Table 8: Total costs of Module C3.

	Description	Gerador de Preços – on site processing (€/m^3)	Waste Processing Companies (€/m^3)
C3	Construction and demolition waste (CDW) site classification (sorting by material)	2,40	-
	Waste processing (crushing)	2,37	17,60

Table 9: Total costs of Module C4.

C4	Waste delivery in licensed operator fee (Gerador de Preços)	9,34 €/m^3
	Cost of receiving CDW (companies in the waste management sector)	15,00 €/m^3

Validation of the results

In order to apply the reference unit costs obtained in the present work, these values were tested in a portfolio school building. In an attempt to approximate the obtained results with the real outcome, a method that divides demolition quantities into categories was used, as in Tables 10 and 11, where it is verified that demolition mean costs tend to decrease as higher quantities are studied, reinforcing the earlier analysis. As for Table 11 this decrease is not so clear, in some cases, because it is a sample with very few values per category.

For the calculation of the total costs, the reference values obtained in this work were used. Table 12 shows the total costs for each module: 71.887,70€ (module C1), 21.907,20€ (module C2), 39.657,90€ (module C3) e 25.200,00€ (module C4).

Thus, considering a scenario where part of the waste is incorporated in construction site and the rest is sent for processing in a licensed operation center, the expected total cost of the end-of-life of structural elements of reinforced concrete is 133.452,80€.

Table 10: Mean unit costs by quantity category (m^3).

	Solid slab	Slab of beam	Ground floor	Beams	Pillars	Concrete walls	Stairs	Outer walls	Platband
Mean (€/m^3):	198,89	40,55	92,25	199,95	186,57	174,30	153,97	207,00	209,13
Category A (<99,99m^3)	204,89	46,32	141,78	208,26	193,78	182,46	153,97	244,58	209,13
Category B (100 a 199,99m^3)	213,35	-	92,43	25,52	42,54	133,50	-	-	-
Category C (>200m^3)	26,94	31,90	58,99	-	-	-	-	56,71	-

Table 11: Mean unit costs by quantity category (m^2).

	Solid slab	Slab of beams	Ground floor	Roof	Stairs
Mean (€/m^2):	84,42	24,51	23,37	21,48	36,88
Category X (<100m^2)	93,12	27,41	15,12	29,77	28,36
Category Y (100 a 1000m^2)	28,36	22,33	28,44	17,37	48,24
Category Z (>1000m^2)	70,89	-	19,90	13,13	-

Table 12: Total cost of reinforced concrete structure demolition of a school building.

Module	Description	Quantity (m^3)	Unit cost (€/m^3)	Total cost (€)	Total cost per module (€)
Module C1	Cost of demolition of structural elements of reinforced concrete (selective demolition)	-	-	71 887,70€	71 887,70€
Module C2	Cost of transport with container	1680m^3	13,04€/m^3	21 907,20€	21 907,20€
Module C3	Cost of on site CDW classification (sorting)	2950m^3	2,40€/m^3	7 080,00€	39.657,90€
	Cost of on site processing of inert waste	1270m^3	2,37€/m^3	3 009,90€	
	Cost of processing in recycling center	1680m^3	17,60€/m^3	29.568,00€	
Module C4	Cost of landfill	1680m^3	15,00€/m^3	25.200,00€	25.200,00€

6. Conclusions

In the first place, it is concluded that LCCA methodology proposed by the standard EN 16627 (2015) is applicable to the case study, verifying its applicability to the end-of-life stage of the concrete structure of school buildings. Although this standard refers to an asset as a single building, it is possible to adapt the methodology to the portfolio of public school buildings studied, concluding that the standard is a tool that can be interpreted and adapted according to the requirements of the stakeholders.

The end-of-life stage includes the deconstruction (module C1), transport (module C2), waste processing (module C3) and disposal (module C4). The collection of costs was based on different sources of information. After the analysis it was possible to obtain mean costs for each module, which stand as unit reference values for public school buildings.

The unit reference costs of module C1, obtained through ProNIC database, were between 40,55€/m^3 and 209,13€/m^3, between 21,48€/m^2 and 84,42€/m^2 and between 5,40€/m and 38,47€/m, for the several units of measurement for the elements in study, showing differences of 18% to 54% when compared to unit costs suggested by the public database Gerador de Preços. These reference values vary depending on the quantity of waste produced. For a higher amount of waste there is a reduction of unit costs. For the remaining modules, companies in the waste management sector were consulted, obtaining unit cost for the transport of waste (module C2) of 13,04€/m^3, unit cost of waste processing (module C3) of 17,60€/m^3, which represents the total cost of entering inert waste at the treatment center plus the average cost of the treatment process of waste. The unit cost obtained for landfilling (module C4) was 15,00€/m^3.

Finally, it is verified the applicability of the reference values obtained in this study to a school that belongs to the portfolio, obtaining a total deconstruction and demolition cost (module C1) of 71.887,70€, a total transport cost (module C2) of 21.907,20€ and a total cost of waste processing (module C3) of 39.657,90€. Assuming the alternative scenario, in which 57% of inert waste is conducted to landfill (module C4), a total cost of 25.200,00€ would be obtained.

The total cost of the end-of-life stage of concrete structure elements (considering recycling operations) was 133.452,80€. Module C1 is the one that has the most impact on the total cost, with a weight of 54%. The use of the reference values at constant prices, corrected for 2018, is important in this assessment, allowing a closer comparative analysis of the current market reality.

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